Dewberry

PROJECT REPORT

For the

National Oceanic and Atmospheric Administration Coastal Services Center

In Partnership with:

Delaware Department of Natural Resources and Environmental Control

Prepared for:
NOAA CSC

Prepared by:
Dewberry
1000 Ashley Blvd., Suite 801
Tampa, Florida 33602-3718

Report Date: July 6, 2011

Table of Contents

Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (LiDAR) technology for the Bombay Hook National Wildlife Refuge project area. Four-band orthophotos were collected for the project area with a resolution of 25 centimeters.

The LiDAR data were processed to a bare-earth digital elevation model (DEM) that included ground and water LiDAR points.

All data was formatted according to a project supplied tile grid with each tile covering an area of 1700 m by 1700 m. Several tiles were added to the original tile grid in order to fully cover the project boundary. A total of 101 tiles were produced for the project encompassing an area of approximately 177 square kilometers. There are only 99 LAS and DEM tiles as two of the tiles represent small slivers of the project boundary that are completely over water. As there were no LiDAR returns from the water in these two tiles, there were no LAS or DEM tiles produced.

The Project Team

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for orthophoto production, breakline production, Digital Elevation Model (DEM) production, quality assurance, and the final LAS classification of the data.

Dewberry's IES offices completed ground surveying for the project and delivered surveyed checkpoints. Their task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model and horizontal accuracy testing of the final orthophoto products. Note that a separate Survey Report was created for this portion of the project.

Terrapoint completed LiDAR data acquisition and data calibration for the Bombay Hook project area. Note that separate reports for the acquisition, calibration, and geodetic control of the LiDAR have been created for this portion of the project.

Richard Crouse & Associates (RCA) completed imagery data acquisition and ABGPS and IMU processing for the Bombay Hook project area. Note that separate reports for the acquisition and ABGPS and IMU processing have been created for this portion of the project.

Survey Area

The project area addressed by this report falls within Kent County, Delaware and covers the Bombay Hook National Wildlife Refuge and surrounding areas.

Date of Survey

The LiDAR aerial acquisition was conducted from Apr. 18, 2011 thru Apr. 20, 2011. The imagery acquisition was conducted on May 7, 2011.

Datum Reference

Data produced for the project were delivered in the following reference system.

> **Horizontal Datum:** The horizontal datum for the project is North American Datum of 1983 (NAD 83) NSRS2007
>
> **Vertical Datum:** The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)

Coordinate System: Delaware State Plane (FIPS 0700)
Units: Horizontal units are in meters, Vertical units are in meters.
Geiod Model: Geoid09 (Geoid 09 was used to convert ellipsoid heights to orthometric heights).

LiDAR Vertical Accuracy

For the Bombay Hook Project, the tested $RMSE_z$ for all checkpoints equaled **0.07 m** compared with the 0.09 m specification; and the FVA computed using $RMSE_z$ x 1.9600 was equal to **0.14 m**, compared with the 0.18 m specification.

For the Bombay Hook Project, the tested CVA computed using the 95th percentile was equal to **0.11 m,** compared with the 0.18 m specification.

Orthophoto Horizontal Accuracy

For the Bombay Hook Project, the tested RMSEr equaled **0.223 m** compared with the 1.155 m specification and the ACCURACYr, computed using RMSEr x 1.7308, tested **0.387 m** compared with the 2 m specification.

Project Deliverables

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – GRID Format)
3. 4-band Orthophotos with 25 cm resolution (TIFF and IMG formats)
4. Raw Imagery
5. Control & Accuracy Checkpoint Report & Points
6. Metadata
7. Project Report (Acquisition, Processing, QC)
8. Project Extents
9. Flightline Data with GPS times
10. Mosaic lines

1 Project Tiling Footprint

One hundred and one (101) tiles were delivered for the project. Each tile's extent is 1700 meters by 1700 meters.

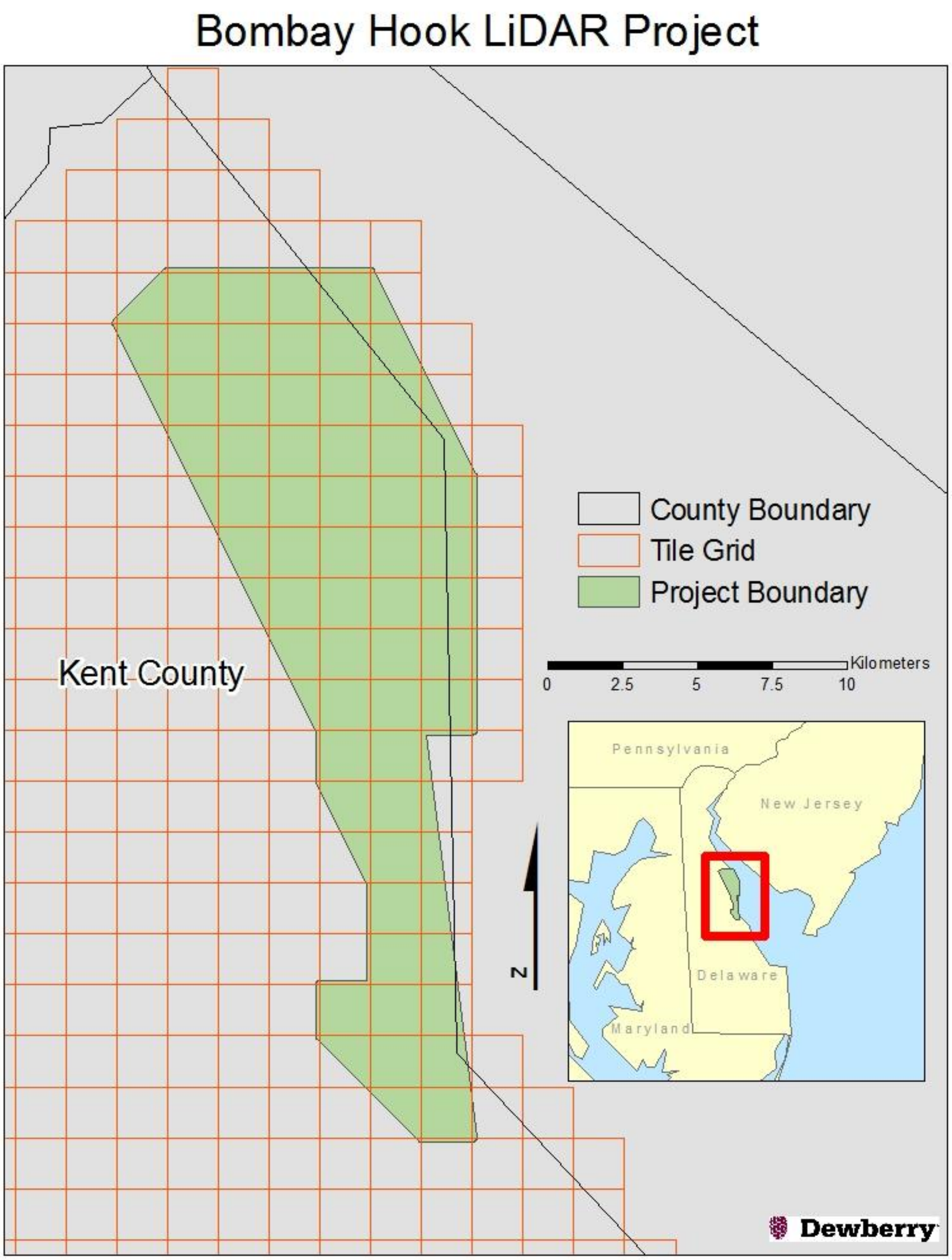


Figure 1: Project Map

1.1 List of delivered tiles (101):

846
847
848
825
826
827
828
805
806
807
808
787
788
789
790
769
770
771
772
751
752
753
732
733
734
712
713
714
715
693
694
695
696
696a
674
675
676
677
677a
654
655
656
657
658
658a
635
636
637
638
639
639a
615
616
617
618
619
620
620a
596
597
598
599
600
601
576
577
578
579
580
581
582
557
558
559
560
561
562
563
538
539
540
541
542
543
544
544a
521
522
523
524
525
526
526a
505
506
507
508
508a
508b
582a*
601a*

Note: Tiles with an (*) are not included in the LAS or DEM deliverables. These tiles represent small slivers of the project boundary that cover water. As there were no LiDAR returns from the water in this area, these two tiles could not be created for the LAS or DEMs as the DEMs are created directly from the LAS.

2 LiDAR Processing & Qualitative Assessment

2.1 Data Classification and Editing

LiDAR mass points were produced to LAS 1.2 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, or 10, including vegetation, buildings, etc.
- Class 2 = Ground, includes accurate LiDAR points in overlapping flight lines
- Class 7 = Noise, low and high points
- Class 9 = Water, points located within collected breaklines
- Class 12 = Overlap points whose scan angle exceeds 20 degrees.

The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing project defined tile boundary index encompassing the entire project areas. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and divided into file size optimized tiles. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine removes any obvious outliers from the dataset first. Next, all points with a scan angle greater than 20 degrees are classified to a separate class so that they are not used during the ground routine. Points with a scan angle greater than 20 degrees have a greater potential for error or causing issues in the ground surface and therefore are not used in the ground surface. After low/noise points and high scan angle points are classified, the ground layer is extracted from the point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption is that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

The following fields within the LAS files are populated to the following precision: GPS Time (0.000001 second precision), Easting (0.01 foot precision), Northing (0.01 foot precision), Elevation (0.01 foot precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded). The LAS file also contains a Variable length record in the file header.

Dewberry utilizes a variety of software suites for data processing. The LAS dataset was received and imported into GeoCue task management software and tiled into 1,700 m by 1,700 m tiles for processing in Terrascan. Each tile was imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water.

2.2 Qualitative Assessment

Dewberry qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital elevation model (DEM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model.

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR nominal point spacing for this project is 1 point per 0.75 square meters. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional elevation mapping technologies and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the dataset is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DEM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the entire bare-earth was measured; only that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a combination of statistical and visualization processes. This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but Dewberry can also find where the data meets and exceeds expectations.

2.3 Analysis

Dewberry utilizes GeoCue software as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. Dewberry uses Microsoft SQL Server as the database of choice. Specific analysis is conducted in Terrascan and QT Modeler environments.

Following the completion of LiDAR point classification, the Dewberry qualitative assessment process flow for the Bombay Hook LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the Bombay Hook LiDAR project conform to the specifications outlined below.

- Format, Echos, Intensity
    - LAS format 1.2, point data record format 1
    - Point data record format 1
    - Multiple returns (echos) per pulse
    - Intensity values populated for each point
- ASPRS classification scheme
    - Class 1 – unclassified
    - Class 2 – ground
    - Class 7 – Noise
    - Class 9 – Water
    - Class 12 – Overlap
- Projection
    - Datum – North American Datum 1983, NSRS2007 adjustment
    - Projected Coordinate System – State Plane Delaware (0700)
    - Units – Meters
    - Vertical Datum – North American Vertical Datum 1988, Geoid 09
    - Vertical Units - Meters
- LAS header information:
    - Class (Integer)
    - GPS Week Time (0.0001 seconds)

- Easting (0.01 foot)
- Northing (0.01 foot)
- Elevation (0.01 foot)
- Echo Number (Integer 1 to 4)
- Echo (Integer 1 to 4)
- Intensity (8 bit integer)
- Flight Line (Integer)
- Scan Angle (Integer degree)

2. *Data density, data voids:* The LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" which creates a 3-dimensional data model derived from Class 2 (ground points) and class 9 (water points) in the LAS files. Grid spacing is based on the deliverable requirement for the final DEMs. For the Bombay Hook LiDAR project it is 1 square meter.

    a. Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. These are considered to be acceptable voids.

3. *Bare earth quality:* Dewberry reviewed the cleanliness of the bare earth to ensure the ground has correct definition, meets the project requirements, there is correct classification of points, and there are less than 5% residual artifacts.

    a. *Noise:* Dewberry identified a few areas that visually appear noisy in the DEMs and surface models (Figure 2). These areas are generally vegetated and may also be marsh (Figure 3). By using cross sections and analyzing the full point cloud (Figure 4), Dewberry has determined the lowest available points have been classified to ground in these areas and that lower points generally are not available in this areas.

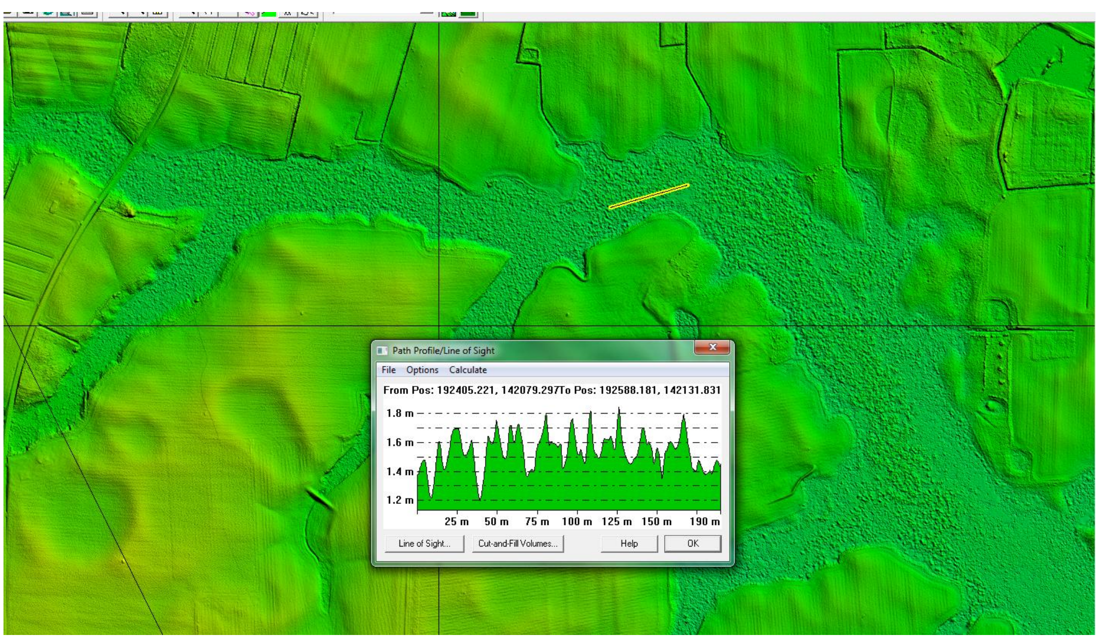


Figure 2 – Ground model of tile LAS_540 colored by elevation. The profile illustrates an area that visually appears noisy in the bare earth surface model.

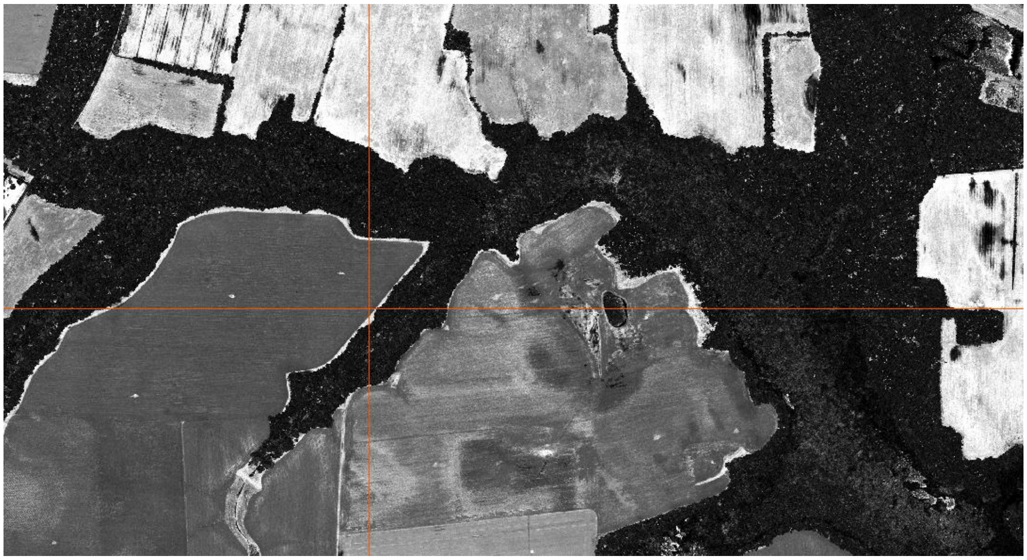


Figure 3 – Intensity imagery of tile LAS_540. The area that appears to be visually noisy in the bare earth surface model is a marsh area covered with vegetation.

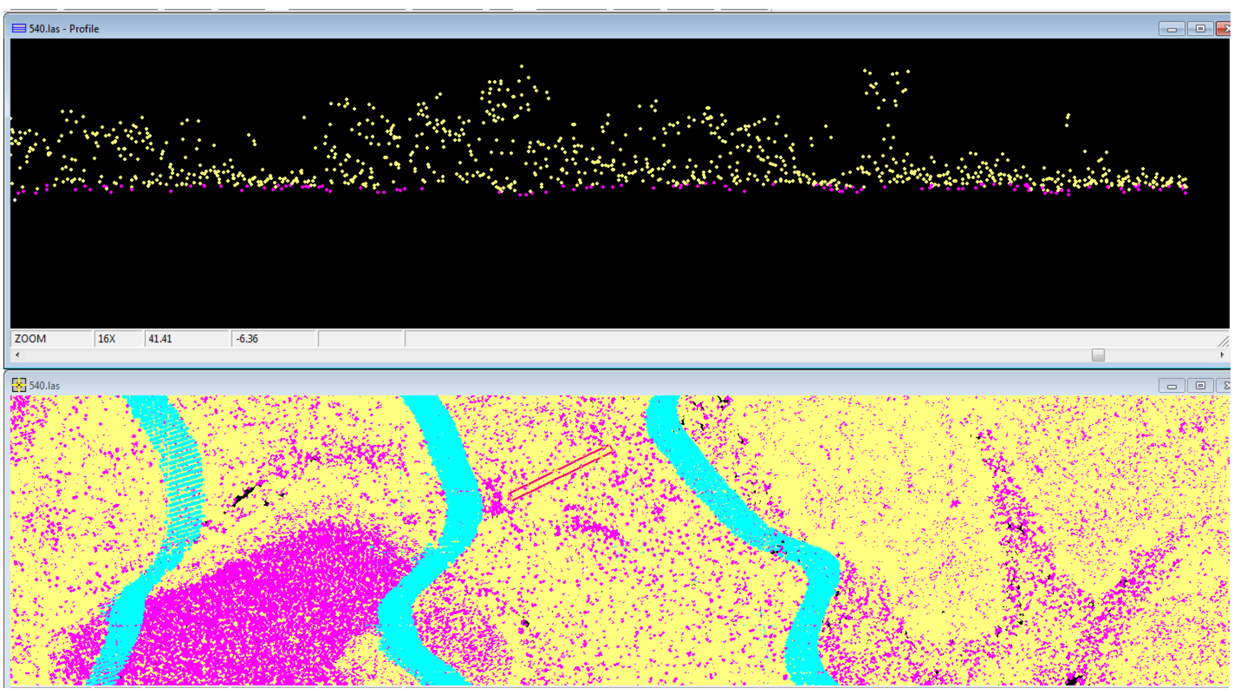


Figure 4 – The top image shows a profile colored by classification that was taken in tile LAS_540. The bottom image shows an overview of the area, colored by classification. Unclassifed-yellow, ground-purple-overlap-turquoise. The profile shows that while the ground appears noisy, only the very lowest points are being used to create the ground surface. This implies that the actual ground is very textured and bumpy in this geographic area.

b. *Relative Accuracy:* Dewberry verified the relative accuracy of the entire project through the use of Delta Z orthos. Delta Z orthos are created in GeoCue and look at overlapping points. Overlapping points that are within a specified threshold of each other are colored green and those exceeding the specified threshold are colored yellow or red. For the Bombay Hook LiDAR project, a threshold of 5 cm was used as this was the requirement outlined by project specifications for adjoining swaths. All points within 1 square meter that were within 5 cm of each other were colored green. Points that were between 5 cm and 10 cm of each other were colored yellow and points exceeding 10 cm were colored red. Points along ditches, embankments, or other sloped areas are expected to show red when the slope within a 1 square meter area exceeds 10 cm. As Figure 5 shows, the Delta Z orthos for the Bombay Hook LiDAR project area are all acceptable.

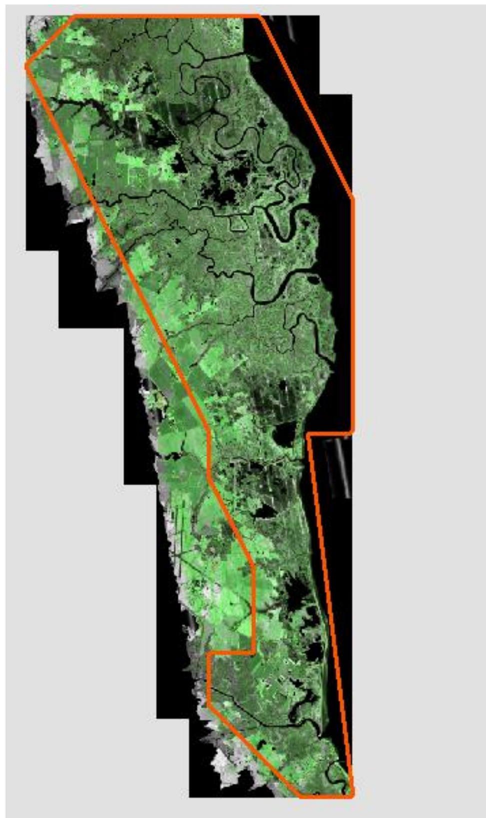


Figure 5-Delta Z orthos for the Bombay Hook LiDAR Project area. The green indicates adjacent points are within 5 cm of each other.

c. *Flight Line Ridge:* One flight line ridge was identified in the dataset. The project requirement for relative accuracy between adjoining flight lines was 5 cm. The Delta Z orthos illustrated that the project met this requirement with no flight lines consistently exceeding the requirement. The isolated ridge that is visible in the surface model is generally within 5 cm and never exceeds 10 cm at any given location. An example is shown in Figure 6 below.

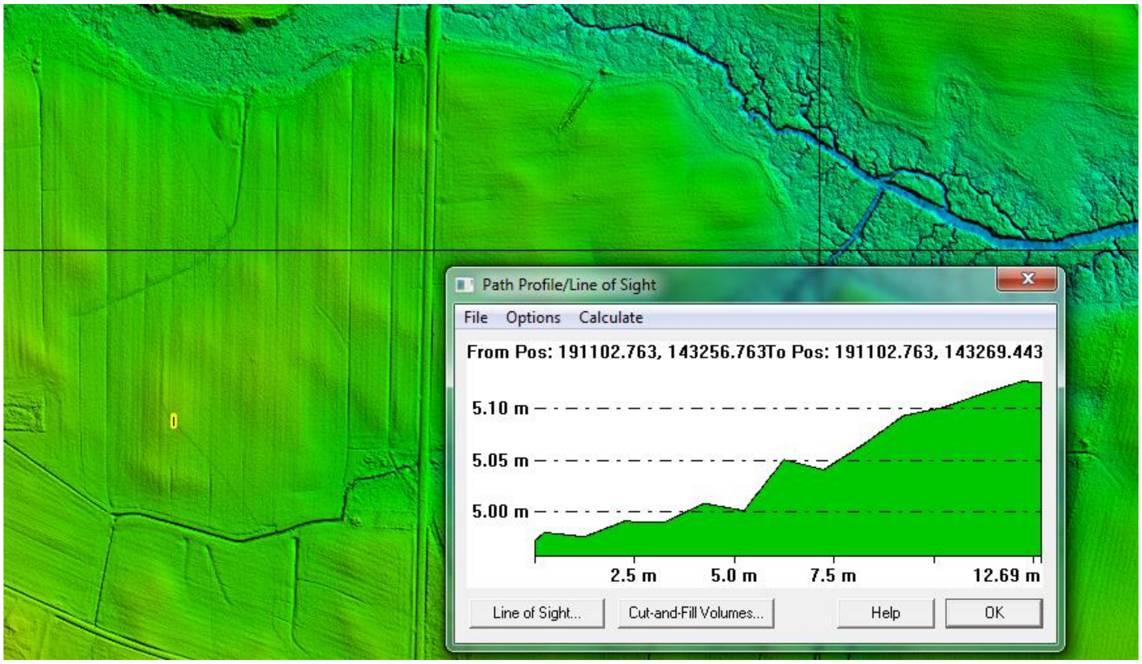


Figure 6- One flight line ridge was identified in tiles LAS_522 and LAS_539. The profile shows that the ridge is within 5 cm. No location could be identified where the ridge exceeded 10 cm.

2.4 Conclusion

The dataset conforms to project specifications for format and header values. The spatial projection information and classification of points is correct. Delta Z orthos show that the relative accuracy of adjoining flightlines are within the project specifications of 5 cm. No issues were identified in the review of the bare earth surface models that would negatively impact the usability of the dataset. Areas that may appear noisy have been validated to be using the lowest points from the full point cloud to create the bare earth surface.

3 Survey Horizontal and Vertical Accuracy Checkpoints

PT. #	NORTHING	EASTING	ELEVS.
	STATE PLANE Delaware		
POINT ID	NORTHING (M)	EASTING (M)	ELEVATION (M)
CP-1	143657.329	191463.586	3.699
CP-2	143813.585	197998.533	0.821
CP-3	116951.761	200680.419	1.908
CP-4	120817.786	197910.075	0.726
CP-5	130394.952	200530.753	1.426
CP-6	138622.882	193720.005	0.728
CP-7	137153.125	200236.125	1.081
CP-8	140275.739	195871.301	0.148

Table 1- Bombay Hook surveyed checkpoints that were used for both LiDAR vertical accuracy testing and Ortho horizontal accuracy testing.

4 LiDAR Vertical Accuracy Statistics & Analysis

4.1 Background

Dewberry tests and reviews project data both quantitatively (for accuracy) and qualitatively (for usability).

For quantitative assessment (i.e. vertical accuracy assessment), eight (8) check points were surveyed for the project and are located within multiple land cover categories, including open terrain, vegetation, and marsh. The checkpoints were surveyed for the project using RTK survey methods. A survey report was produced which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area, using the “dispersed method” of placement.

4.2 Vertical Accuracy Test Procedures

FVA (Fundamental Vertical Accuracy) is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSEz) of the checkpoints x 1.9600. For the Bombay Hook LiDAR project, vertical accuracy must be 18 cm or less based on an RMSEz of 9 cm x 1.9600.

CVA (Consolidated Vertical Accuracy) is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all land cover categories combined. The Bombay Hook LiDAR Project CVA standard is 18 cm at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

Checkpoints were surveyed in several land cover types, including open terrain or urban, vegetation, and marsh. As there were only 8 checkpoints for the project and both FVA and CVA have to meet 18cm accuracy requirements, all 8 checkpoints were used to calculate both the FVA and CVA. All 8 checkpoints were tested using both the RMSEz and 95^{th} percentile method.

The relevant testing criteria are summarized in Table 2.

Table 2 — Acceptance Criteria

Quantitative Criteria	Measure of Acceptability
Consolidated Vertical Accuracy (CVA) using all checkpoints	18 cm (based on combined 95^{th} percentile)
Fundamental Vertical Accuracy (FVA) using all checkpoints	18 cm (based on RMSEz * 1.9600)

4.3 Vertical Accuracy Testing Steps

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications. Figure 7 shows the location of the checkpoints.
2. Next, Dewberry interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 8 checkpoints.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed FVA and CVA values.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

Figure 7 shows the location of the QA/QC checkpoints within the project area.

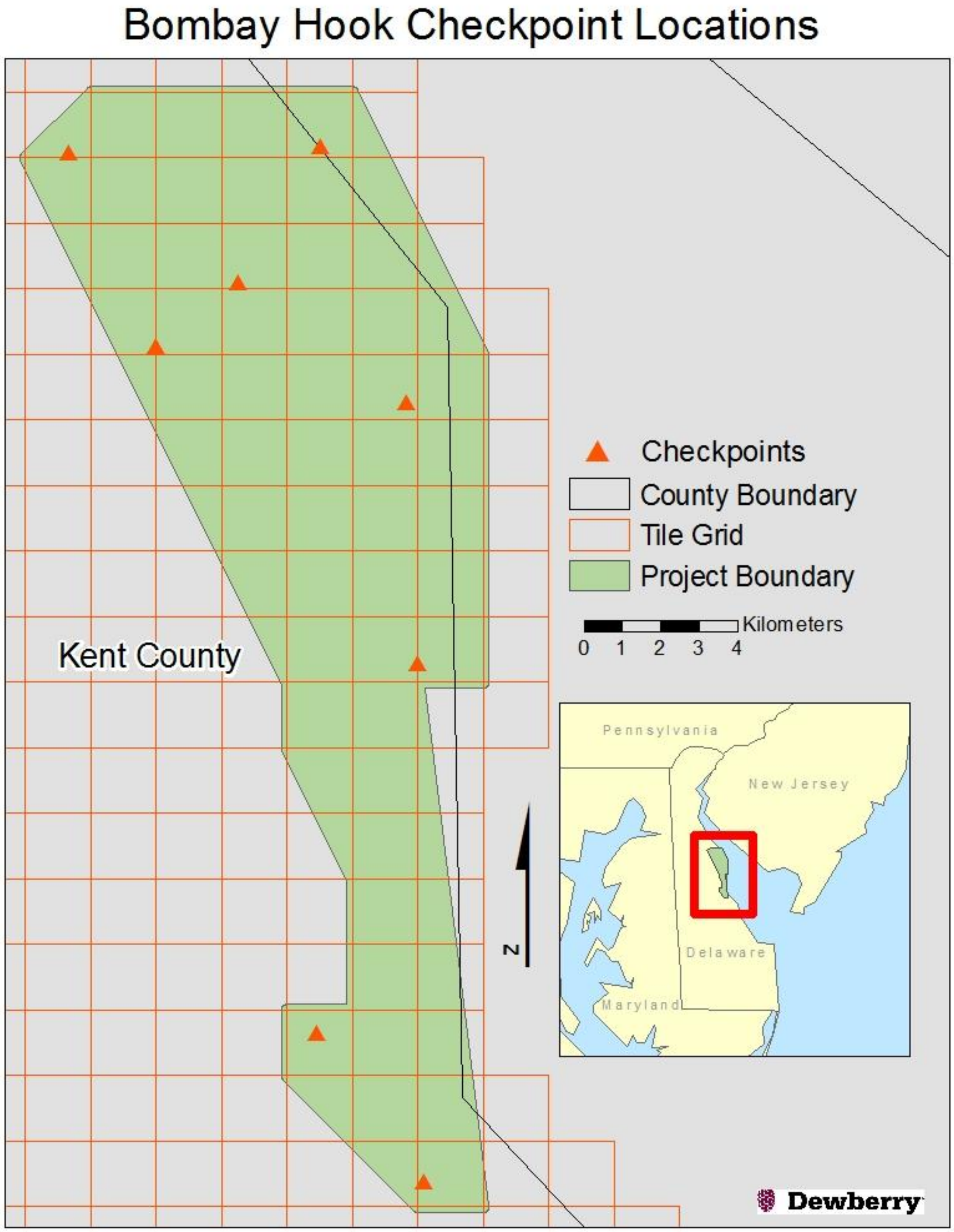


Figure 7 – Location of QA/QC Checkpoints

4.4 Vertical Accuracy Results

Table 3 summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the LiDAR LAS files.

Table 3 — FVA and CVA Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.18 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec= 0.18 m
Consolidated	8	0.14	0.11

The $RMSE_z$ for all checkpoints tested 7 cm, within the target criteria of 9 cm. Compared with the 18 cm specification, the FVA tested 14 cm at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 18 cm specification, CVA for all checkpoints tested 11 cm at the 95% confidence level based on the 95th percentile.

Figure 8 illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data. This shows that the majority of LiDAR elevations were within +/- 10 cm of the checkpoints elevations, but there was one outlier where LiDAR and checkpoint elevations differed by more than +/- 10 cm.

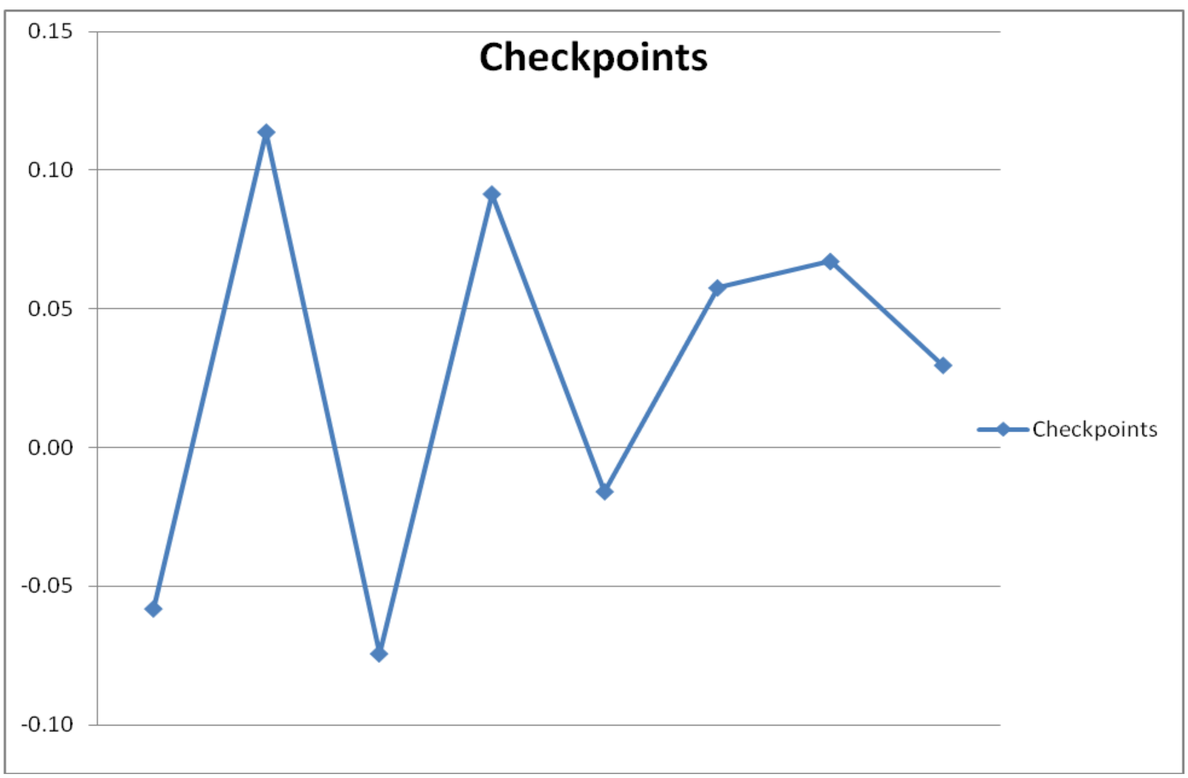


Figure 8 – Magnitude of Elevation Discrepancies

Table 4 lists the 5% outliers that are larger than the 95th percentile, or 0.73 feet.

pointNo	NAD 1983 NSRS2007 Delaware State Plane Coordinate System		NAVD88	LiDAR Z (m)	Delta Z
	Easting - X (m)	Northing - Y (m)	Survey Z (m)		
CP-2	197998.533	143813.585	0.821	0.935	0.114

Table 4 — 5% Outliers

Table 5 provides overall descriptive statistics.

100 % of Totals	RMSE (m) FVA Spec=0.09 m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.07	0.06	0.04	-0.38	0.07	8	-0.07	0.11

Table 5 — Overall Descriptive Statistics

Figure 9 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -7 cm and a high of +11 cm, the histogram shows that the majority of the discrepancies are on the positive side.

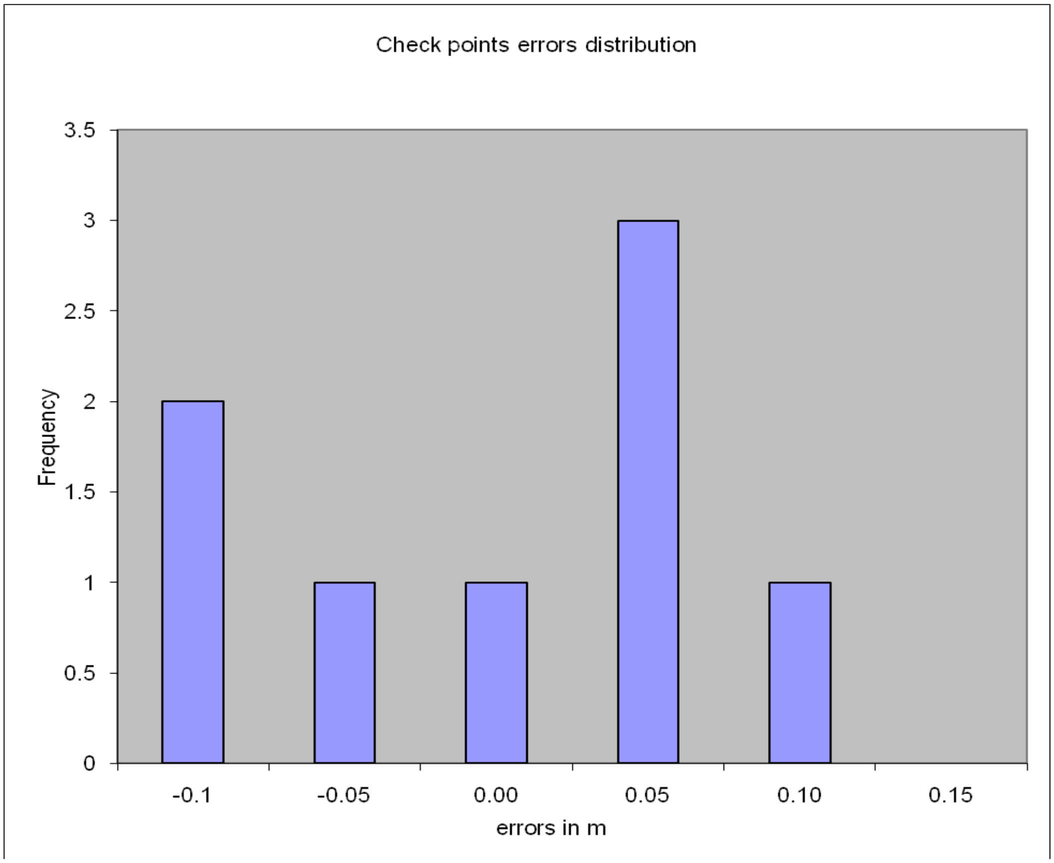


Figure 9 — Histogram of Elevation Discrepancies within errors in meters

4.5 Conclusion

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the Bombay Hook LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

5 Breakline Production & Qualitative Assessment Report

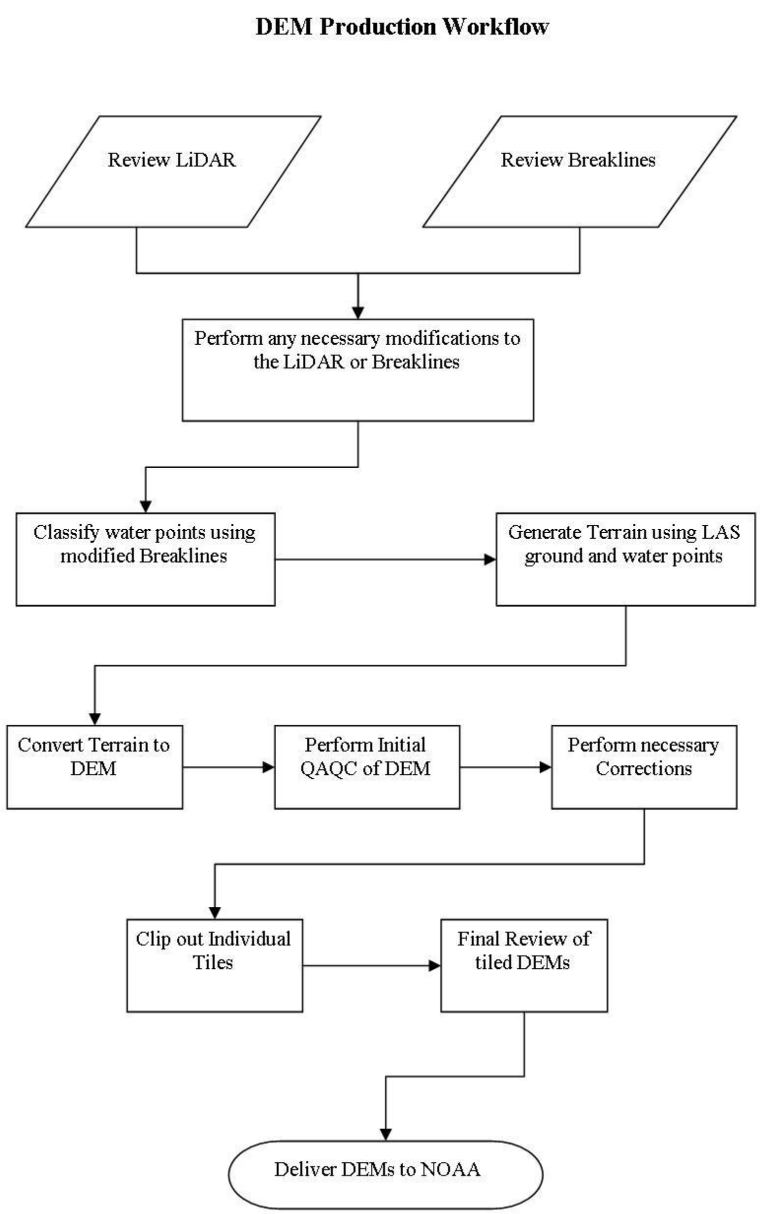
5.1 Breakline Production Methodology

Dewberry used GeoCue software to develop ortho-imagery from the LiDAR intensity. These intensity images were used to collect 2D hydrographic breaklines. The breaklines were only used to classify LiDAR points as class 9, water, and were not used to support the bare earth surface or provide hydro-flattened or hydro-enforced DEMs.

6 DEM Production & Qualitative Assessment

6.1 DEM Production Methodology

Dewberry's utilizes ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper.



1. <u>Classify Water Points</u>: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.

2. Terrain Processing: A Terrain will be generated using the LAS data that has been imported into Arc as a Multipoint File. If the final DEMs are to be clipped to a project boundary that boundary will be used during the generation of the Terrain.
3. Convert Terrain to Raster: Convert Terrain to raster.
4. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.
5. Extract Individual Tiles: Individual Tiles will be extracted from the zones utilizing the Dewberry created tool.
6. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

6.2 DEM Qualitative Assessment

Dewberry performed a comprehensive qualitative assessment of the DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in Arc GIS and Global Mapper software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process, that all files are readable, and that no artifacts exist between tiles.

6.3 DEM QA/QC Checklist

Project Number/Description: Bombay Hook LiDAR Project
Date:______07/01/2011_____
Overview

☒ Correct number of files is delivered and all files are in ESRI GRID format
☒ Verify Raster Extents
☒ Verify Projection/Coordinate System

Review

☒ Manually review bare-earth DEMs with a hillshade to check for issues or any general anomalies that may be present.
☒ DEM cell size is 1 meter
☒ Perform final overview in Global Mapper to ensure seamless product.

Metadata

☒ Project level DEM metadata XML file is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc.

Completion Comments: Complete – Approved

7 Digital Orthophotos

7.1 Orthophoto Production and Methodology

Raw imagery was collected by Richard Crouse & Associates (RCA). RCA collected 4-band imagery (red, green, blue, and near infrared) using an Intergraph DMC sensor. The full acquisition, airborne GPS (ABGPS), and inertial measurement unit (IMU) processing is documented in a separate report and included in the final deliverables.

ImageStation Automatic Triangulation (ISAT) software issued by Intergraph Z/I Imaging, Inc. was utilized to perform aerotriangulation. ISAT used the camera calibration report, raw imagery and the control points mentioned above to produce a bundle block adjustment solution which is necessary for both viewing the aerial photographs in stereo and for producing the digital orthophotography. Aerotriangulation was accomplished in order to meet the required accuracy of 2 meters.

Dewberry produced the orthophotos with Image Station Ortho Pro software, which utilizes the solution produced by ISAT, the raw imagery, and a Digital Elevation Model (DEM) that was produced from this project's LiDAR. The resulting orthos were then created with a 25 centimeter pixel resolution. The completed orthos were then joined seamlessly by using a "feathering" technique that blended the tonal values across the mosaic lines. A tile grid was used to create the bounding coordinates of each image. The resulting 101 mosaics then had an overall tonal adjustment applied based on tonal parameters to radiometrically balance the color.

The orthophotos are reviewed in ArcMap to ensure artifacts, minor mis-alignments, inappropriate mosaic lines, ghosting, smears, or radiometry issues are not present in the final orthophoto dataset. Minor issues are corrected with Photo Shop software. Major issues, such as large mis-alignments, could be indicators the AT, calibration, or mosaic lines have issues and would require subsequent review and corrective action. No issues were identified in the dataset that required corrective actions or Photo Shop.

8 Orthophoto Horizontal Accuracy Statistics & Analysis

8.1 Background

Dewberry tests and reviews project data both quantitatively (for accuracy) and qualitatively (for usability).

For quantitative assessment (i.e. horizontal accuracy assessment), eight (8) check points were surveyed for the project and are located at features that are photo-identifiable. The checkpoints were surveyed for the project using RTK survey methods. A survey report was produced which details and validates how the survey was completed for this project.

The same survey control that was used in the LiDAR vertical accuracy testing was used in the Ortho horizontal accuracy testing. Figure 7 in section 4.3 shows a map of the checkpoint locations for Bombay Hook.

8.2 Horizontal Accuracy Test Procedures

The accuracy requirements are summarized in Table 6.

Table 6 — Acceptance Criteria

Quantitative Criteria	Measure of Acceptability
ACCURACYr $\leq$ 2 meters	RMSEr * 1.7308

8.3 Horizontal Accuracy Testing Steps

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC horizontal checkpoints in accordance with the project's specifications. Figure 7 in section 4.3 shows the location of the checkpoints.
2. Using maps and photos of each checkpoint taken by the surveyor, Dewberry identifies the same location of the checkpoint on the imagery. In order to do this successfully, the checkpoints must be located at photo-identifiable features such as corners of paint strips or driveways.
3. Dewberry analysts collect the x and y coordinates of each checkpoint location from the orthophoto dataset. These coordinates are compared to the surveyed coordinates of the checkpoint locations and errors are computed.

8.4 Horizontal Accuracy Results

Table 7 shows the tested horizontal accuracy results from a comparison of the surveyed checkpoint coordinates to the photo-identified coordinates.

Bombay Hook, Orthophoto Horizontal Accuracy Assessment

References: FGDC's Geospatial Positioning Accuracy Standards
National Standard for Spatial Data Accuracy (NSSDA), FGDC-STD-007.3-1998

	QA/QC Survey Checkpoints Surveyed by Dewberry SPCS Delaware NAD 83		Orthophoto Coordinates Measured by Dewberry SPCS Delaware NAD 83		Orthophoto minus surveyed coordinates SPCS Delaware NAD 83		Discrepancies Squared as required for RMSE calculations	
Point Number	Northing (y) Meters	Easting (x) Meters	Northing (y) Meters	Easting (x) Meters	Δy (Northing) Meters	Δx (Easting) Meters	$\Delta y^2 (m^2)$	$\Delta x^2 (m^2)$
cp-1	191463.59	143657.33	191463.52	143657.00	-0.069	-0.329	0.0048	0.1082
cp-2	197998.53	143813.59	197998.46	143813.29	-0.069	-0.299	0.0048	0.0894
cp-3	200680.42	116951.76	200680.49	116951.51	0.067	-0.255	0.0045	0.0650
cp-4	197910.08	120817.79	197909.96	120817.76	-0.113	-0.024	0.0128	0.0006
cp-5	200530.75	130394.95	200530.73	130394.78	-0.023	-0.173	0.0005	0.0299
cp-6	193720.01	138622.88	193720.00	138623.03	-0.007	0.147	0.0000	0.0216
cp-7	200236.13	137153.13	200235.99	137153.00	-0.133	-0.126	0.0177	0.0159
cp-8	195871.30	140275.74	195871.15	140275.75	-0.152	0.014	0.0231	0.0002
						Sums	0.0682	0.3309
All coordinates in meters			Horizontal Accuracy Acceptance Criteria			MSE	0.0085	0.0414
			RMSEx and RMSEy must be ≤ .668 meters			RMSEyx (m)	0.0923	0.2034
			RMSEr must be ≤ 1.155meters			RMSEr (m)	per NSSDA	0.2233
RESULT:		PASS	ACCURACYr must be ≤ 2 meters			ACCURACYr (m)	per NSSDA	0.3865

Table 7 — Orhtophoto Horizontal Accuracy Assessment errors in meters

8.5 Conclusion

Based on the horizontal accuracy testing conducted by Dewberry, the orthophoto dataset for the Bombay Hook Project satisfies the project's pre-defined horizontal accuracy criteria. The project has an ACCURACYr of 0.3865 meters, which is well within the 2 meter requirement.